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COMPLETE SPECIFICATION

Aircraft Guidance System

I, ROBLEY DUNGLISON EVANS, a Citizen of the United States of America of 15 Hickory Lane, Belmont, Massachusetts, United States of America do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to an aircraft guidance system for determining, with the aid of radiant energy, the range and positional information of the aircraft with respect to a source of the radiation.

Though numerous types of radiant energy ranging devices have long been proposed and utilised, including conventional types of radar, sonar, proximity devices, altimeters and related equipment, to mention but a few, these are all generally subject to the principle disadvantage that, if the distance or range between objects becomes very small, not only does the accuracy of the apparatus become markedly reduced, but there are serious limitations in the measurement of very small ranges resulting from such factors, among others, as "spurious clutter" in the case of radar and sonar systems, finite wave length of the radiant energy in the case of other systems, and other limiting factors.

In prior ranging systems, including those of the above-described type, moreover, the signal indications are dependent upon the strength of received signal and are subject to serious deleterious effects when other objects or background radiation, including spurious radiation present in the ranging medium, occur; such systems also being dependent for sensitivity upon the signal strength and appropriate operational condition of the source or transmitter of radiant energy.

An object of the present invention, accordingly, is to provide a new and improved aircraft guidance system to avoid the above-described limitations.

There is provided by the present invention an aircraft guidance system responsive to energy radiated from a given source and having an intensity decreasing with distance from the source in accordance with the function generally represented as $f(r, \mu)$, where r is distance from the source and μ is an attenuation parameter determined by the type of the radiant energy and the medium through which it is radiated, the system comprising three radiant energy detectors differently located on the aircraft and the outputs of which are paired so as to produce two intensity ratio measurements of the radiant energy incident on the detectors, dependent respectively on the azimuth angle and range of the aircraft with respect to the given source, and means for expressing the intensity ratio measurements in accordance with a predetermined relationship, to indicate said azimuth angle and said range of the aircraft.

Preferably a fourth detector is employed located on the aircraft so as to produce together with one of said three detectors, an intensity ratio measurement dependent upon the elevation angle of the aircraft with respect to the source, for any given range and for any given azimuth angle of the aircraft with respect to the source; and wherein said means comprise means for expressing the latter intensity ratio measurement in accordance with a predetermined relationship to indicate the elevation angle of the aircraft with respect to the source.

The invention will now be described with reference to the accompanying drawings,

Figure 1 of which is an isometric schematic view illustrating the invention as applied to aircraft obstacle detection;

Figure 2 is a schematic block diagram of

computing apparatus for use in the system of Figure 1; and

Figures 3, 4 and 5 are graphs, the data of which may either be presented visually for observation or employed in conventional computing apparatus for interpreting the results of the measurements attained in the systems of Figures 1 and 2.

Referring to Figure 1, the invention, as previously mentioned, is shown applied to the important application of the avoidance of obstacles such as mountain peaks, by aircraft; though it will be evident from the following description that the underlying method and basic apparatus of the invention are equally useful in the approach of aircraft to other obstacles or stations such as landing strips, particularly in operations where the distance between the aircraft and whatever is being approached, becomes very small. For illustrative purposes, Figure 1 shows an aircraft I approaching a mountain peak object I', wherein it is desired continually to determine the distance or range between the two objects I and I' and the relative bearing angle. The mountain peak object I' is shown provided with a source or transmitter J of radiant energy that may, for example, be a beacon or source of incoherent electromagnetic radiation such as radio waves, x-rays, gamma rays, infrared waves, or other light waves, both visible and invisible), corpuscular radiations, radioactive radiations, and acoustic waves, not only in the audible range but also in the sub and super-audible ranges.

As will later be pointed out, coherent light energy, as from a laser source J, may also be employed, as may coherent acoustic and other waves. Depending upon the nature of the radiant energy source J, appropriate energy receiving systems or detectors will be provided upon the aircraft I.

In Fig. 1, four such energy detectors are illustrated, a principal detector being located near the nose at I_r, a pair of detectors near the extremities of the aircraft wings at I_a and I_b, and a further detector I_s disposed below the detector I_r on the underside of the aircraift I. The distance or range from the detector I_r to the source J on the mountain top object I' is designated by the symbol r; and the corresponding distances from the other detectors I_a, I_b, and I_s are respectively designated by the symbols r_a, r_b, and r_s. The detectors I_r, I_a, and I_b determine a plane indicated as a dotted triangle, with the spacing between the detectors I_a and I_r being represented by the distance a, and the spacing between the detectors I_r and I_b being represented by the distance b. Though arrangements may be employed with different detector spacings, as later more fully explained, in the preferred example of Fig. 1, the spacing b is made substantially equal to the spacing a and substantially equal to the spacing between the detectors I_a and I_b; whereby the detectors I_r, I_a, and I_b form the vertices of a substantially equilateral triangle, the perpendicular bisector of which may be represented by the upper edge portion of the aircraft, an extension of which is indicated by the dotted line I. The azimuthal or relative bearing angle between the heading of the aircraft object I and the source J at the mountain top object I' is represented by the angle θ lying substantially in the plane formed by the three detectors I_r, I_a, and I_b. When the aircraft is turned in bearing or heading so as to point directly at the source J, the angle θ is 0. The angle of elevation of the aircraft is shown indicated with reference to the dotted line I' through the detector I_s, by the symbol ϕ.

Considering, first, the pair of detectors I_r and I_a, when the detectors are oriented so that the direction a of their spacing has at least a component in the direction r between the aircraft and the object I' so that the ratio of the intensities of the energy received from the source J at the detectors I_r and I_a is a measure of the range r, continual monitoring of that ratio enables a continual determination of the range r, which becomes more sensitive and more accurate as r becomes smaller and smaller and more comparable with the separation distance a, between the detectors I_r and I_a.

In general, the energy transmitted from the source J to the aircraft I will decrease with distance from the source J in accordance with a predetermined function generally represented as $f(r, \mu)$, where μ is an attenuation parameter determined by the type of energy and the nature of the medium through which it is transmitted or, for practical purposes, the nature of the medium in the region between the detectors concerned. Thus, a measurement of the ratio

$$\frac{I_r}{I_a}=\frac{f(r, \mu)}{f(r_a, \mu)},$$

as above mentioned, enables an indication of the distance r as will be more fully hereinafter discussed.

In the case of electromagnetic radiation, the function is generally of the form $\frac{e^{-\mu r}}{r^n}$, where n is generally two (that is, the inverse square law) or some other integer or fraction. The ratio of the intensity of the energy received at detector I_r to that detected at I_a may then be shown to be given substantially by the expression:

$$\frac{I_r}{I_a}=\left(1+\frac{a}{r}\right)^n e^{\mu a},$$

which, it will be noted, is independent of the signal strength of the source J and which depends solely on the known separation a between detectors l_r and l_a and the attenuation parameter μ in the region between the detectors. With these values given, the ratio: l_r/l_a, thus gives a measure of the range or distance r between the objects l and l'.

In view of the independence of source signal strength in the ratio l_r/l_a, it will be clear that the ranging system, provided a signal can be received, will operate with equal efficacy irrespective of weakness, time fluctuations, or other operational defects in the transmitting source J and irrespective of whether some other objects have entered the region between the aircraft and the object l'. This independence is a feature not possible with known types of ranging systems as before explained and would, for example, enable a flight of helicopters continually to monitor the lead helicopter despite the fact that other craft should wander in the path between them and the lead helicopter. Other highly advantageous results following this phenomenon will also be readily apparent in other applications of the invention.

It should be noted, moreover, that while the embodiment of Fig. 1 has been described in connection with the propagation of energy from the transmitting source J at the object l', the invention is equally useful if the aircraft l carries a source or transmitter that reflects energy from the object l' and reradiates the reflected energy to the detectors l_r and l_a, or if some other source reflects energy from the object l' to the detectors disposed upon the aircraft. It should also be observed that the type of modulation or continuous wave operation employed is not significant since the detectors, in accordance with the present invention, measure the intensity of the energy received thereat and determine the ratio of those detected intensities.

In the most common cases, the energy source J will emit in a broad angular pattern and often more or less uniformly in all directions. In those exceptional cases such as for a laser beam whose angular breadth may be less than that subtended by an array of detectors on the aircraft, a rotating beam or beacon can be employed. The energy source J can also be modulated to provide an identification signal which could be read out by a simple auxiliary circuit, without altering the instantaneous measured ratios.

By employing the third detector l_b in the substantially equilateral triangle arrangement of Fig. 1, measurements are made of both the intensity ratio of the energy received at the pair of detectors l_r and l_a and the ratio of intensities received at the pair of detectors l_r and l_b. In the generalised case where the spaces a and b may not be the same, these ratios are given by the following expressions:

$$\frac{l_r}{l_a}=\left(l+\frac{a'}{r}\right)^n e^{\mu a'}$$

and

$$\frac{l_r}{l_b}=\left(l+\frac{b'}{r}\right)^n e^{\mu b'},$$

in which a' and b' are substantially the components or projections of a and b in the direction of r.

In the important case of n being equal substantially to 2 and the distances a, b, and that between l_a and l_b being substantially equal, these reduce to the form:

$$\frac{l_r}{l_a}=\left[l+\left(\frac{a}{r}\right)^2-\frac{2a}{r}\cos\,(150^\circ-\theta)\right]e^{\mu(r_a-r)}$$

$$\frac{l_r}{l_b}=\left[l+\left(\frac{a}{r}\right)^2-\frac{2a}{r}\cos\,(150^\circ+\theta)\right]e^{\mu(r_b-r)}.$$

In this important case, where $\mu(r_a-r)$ and $\mu(r_b-r)$ are small compared with unity, as in the case of radio wave or other incoherent electromagnetic radiation in air, the simultaneous solution of the above expressions provides a direct indication of the distance r and the angle θ.

The type of circuit or circuits employed to effect the ratio measurements and parameter indications above discussed will now be described. Referring to Fig. 2, the detectors l_a and l_b are shown feeding their outputs, representative of the intensity of the energy received thereby to respective ratio circuits 3 and 5 to which the output of the detector l_r is also fed. These ratio circuits may, for example, be of the type described by Robley D. Evans, et al, in Review of Scientific Instruments *10*, 339—344 (1939), or of any other well-known type for obtaining an output representative of the received energy intensity ratios l_r/l_a and l_r/l_b, respectively. The output signals representing these ratios are shown respectively applied by conductors 7 and 9 to the ordinate coordinate input and the abscissa coordinate input of, for example, a computing X—Y plotter 2 of any conventional type.

There will thus be continually entered the ratio l_r/l_a as an ordinate quantity and the ratio l_r/l_b as an abscissa entry providing at the conventional coordinate point indicator of such apparatus, designated by the reference numeral 10, a point which is visually and/or electrically representative of the distance r and angle θ. For the visual presentation, it will be noted that a plurality of successive arcuate contour lines r_1, r_2 and r_3 are shown on the plotter 2 intersecting successively

different bearing angle lines θ_1, θ_2, θ_3, θ_4, etc. The indicator 10 is shown in coincidence with the distance line r_2 and the angle θ_2 indicating the distance between the objects as value r_2 and the azimuth or bearing angle as θ_2.

In Fig. 3, an actual set of data for the plotting computer 2 is presented for the case of the equilateral triangle structure of Fig. 1 showing range contours at $r=10a$, $r=5a$, $r=3a$ and $r=2a$ intersecting bearing angle lines for $\theta=0°$, 2°, 5°, 10°, 20° and 30°.

It will be observed that for smaller distances (the smallest of which is shown by the contour line $r=2a$ in Fig. 3), the apparatus of the present invention becomes increasingly sensitive and accurate, as indicated by the wider spacing of the angle lines and the greater fanning of the arcuate range contour lines. For a distance a of 100 feet, for example, which is entirely feasible with a large jet aircraft, the ratio I_r/I_a is shown in the following Table I to change more significantly for the smaller values of the distance r for each of two exemplary values of the angle θ; namely, $\theta=0°$ (on heading) and $\theta=10°$. The change in this intensity ratio for the 100 feet between a distance or range of 200 feet and 100 feet is much greater than the change in ratio for the 100 feet between a distance of 300 feet and 200 feet.

Specifically, the distance between a range of 300 feet and 200 feet between the objects produces a difference in intensity ratio of 0.428 for the $\theta=0°$ example; where as the intensity ratio changes by 1.616 in the next 100 feet between 200 feet and 100 feet, thus demonstrating the increased sensitivity and accuracy of the present invention as smaller distances are approached and as distinguished from prior art types of ranging systems.

TABLE I

a=100 feet r (ft)	I_r/I_a $\theta=0°$	$\theta=10°$
100	3.732	3.532
200	2.116	2.016
300	1.688	1.622
500	1.386	1.346
1000	1.183	1.163

It has further been found that by applying to the ordinate input of the X—Y plotter 2 the difference between the ratios I_r/I_b and I_r/I_a, as obtained in a subtractor 11, when the ratio circuits 3 and 5 are connected by moving switches S and S′ respectively downward and upward in Fig. 2 (the output of the subtractor 11 being shown applied to the ordinate input of the plotter 2 at 11′), and applying to the abscissa input at 9 the output 13′ of a summer 13 (that gives the sum of the said ratios), a further most convenient and advantageous measure of range and bearing angle can be obtained in the plotter 2.

Circuit elements such as the subtractor 11, the summer 13, as well as time-derivative circuits 20, and others mentioned hereinafter are state-of-the-art stock components.

As is more particularly illustrated in Fig. 4 where the difference and sum of the pairs of ratios are plotted, there are shown, again, contours of range or distance ranging from $r=2a$ to $r=10a$ and intersecting successively increasing angle lines ranging from $\theta=0°$ up to $\theta=30°$. With the systems of Figs. 1 and 2 and this sum and difference ratio determination, it has been found that the difference of the ratios is given by the following expression:

$$\frac{I_r}{I_b}-\frac{I_r}{I_a}=2\left(\frac{a}{r}\right)\sin\theta$$

The sum of the pair of ratios may be shown to be given by the following equation:

$$\frac{I_r}{I_b}+\frac{I_r}{I_a}=2\left[1+\left(\frac{a}{r}\right)^2+2\frac{a}{r}\,(0.866\cos\theta)\right]$$

Examination of the above equations shows that the sum of the ratios is substantially independent of the angle θ over a substantial range, which accounts for the substantially vertical line character of the range contours of Fig. 4. From the above equation for the sum of the ratios, it will be evident that for small angles θ, the bracketed expression depends substantially entirely on the range r and is nearly independent of the angle.

This independence is clearly illustrated in the following Table II, wherein the values of the sum of the ratios is substantially the same irrespective of the angle θ.

TABLE II

a=100 feet r (ft)	$\frac{I_r}{I_b}+\frac{I_r}{I_a}$ $\theta=0°$	$\theta=10°$	$\theta=20°$
100	7.464	7.410	7.256
200	4.232	4.206	4.128
300	3.377	3.359	3.307
500	2.773	2.762	2.731
1000	2.366	2.361	2.346

The expression for the difference of the ratios above presented, however, shows the rather remarkable characteristic of a variation that is inversely proportional to the range r and that is actually proportional to the sine

of the angle θ and thus, for small angles, substantially proportional to the angle itself. This proportionality is, of course, a highly advantageous effect and produces marked changes in the ratio difference proportionately with angle as indicated in the following Table III:

TABLE III

$a=100$ feet	$\frac{l_r}{l_b}-\frac{l_r}{l_a}$		
r (ft)	$\theta=0°$	$\theta=10°$	$\theta=20°$
100	0.000	0.347	0.684
200	0.000	0.174	0.342
300	0.000	0.116	0.228
500	0.000	0.069	0.137
1000	0.000	0.035	0.068

Thus, either with the aid of the predetermined data of Fig. 3 or that of Fig. 4 (with the switches S and S′ in the corresponding positions), coincidence of the appropriate ratio inputs as coordinates with the predetermined range and angle data enables a continual indication of the distance r and angle θ as the aircraft approaches the object l', and with increasing sensitivity as the distance r becomes smaller and more comparable with the separation of the detectors.

Not only may visual indication and measurement of the distance and angle θ be thus presented, but the coordinate input information may be used for simultaneous equation solving in a conventional computer circuit for handling the above equations to provide output signals that enable respective continual indications of the distance r as at the range meter 15 and the bearing angle θ as at the angle meter 17.

In the system of Fig. 2, visual indication of the elevation angle ϕ is provided in a similar computer X—Y plotter 2′ into the abscissa input of which the ratio l_4/l_r is applied, as at 19, from a ratio circuit 21, similar to the ratio circuits 3 and 5 before discussed, into which is fed the output of the respective detectors l_r and l_4. The data effectively stored in the plotter 2′ by the graphical chart there shown enables a determination of the value of the elevation angle ϕ since the distance r is known and may be applied at 23. The range curves or lines r_1, r_2, r_3 are shown on the plotter 2′ as more particularly presented in Fig. 5 for values of $r=10c$ down to $r=2c$. Since the indicator 10′ will coincide with the measured value of the range and the input of the ratio l_4/l_r enables a coincidence thereof with the appropriate range line, the resulting angle ϕ will be indicated along the ordinate.

Again, the output angle ϕ may be electrically read out, as is well known, as in the meter 25.

In those cases where the attenuation parameter μ is not known, as in the presence of an unsuspected attenuating medium between the detectors, the value of μ, as before stated, may be obtained at 23′ through the simultaneous equation solution previously discussed. As one explicit example, this may be effected for the case where the triangular orientation of the three detectors l_r, l_a and l_b is collapsed to a very flat triangle (that is to substantially a colinear array of three detectors) by computing μ from the following intensity ratios:

$$\mu=2\,\frac{\frac{1}{b}\left[\sqrt{\frac{l_r}{l_b}}-l\right]-\frac{1}{a}\left[\sqrt{\frac{l_r}{l_a}}-l\right]}{\sqrt{\frac{l_r}{l_b}}-\sqrt{\frac{l_r}{l_a}}}$$

The use of three detectors l_r, l_a and l_b, from which two independent ratios are derived enables not only a determination of the effective value of the attenuation parameter loss, but alternatively may provide a redundancy mechanism for checking the operational integrity of either of any two paired detectors. More than this, the use of three detectors enables a measurement to be made that can provide a background energy correction for the distance determination, such background energy being analogous to noise or spurious energy present in the path between the aircraft and object l'. If, for example, the ratio l_r/l_a is to be employed as first described to measure the distance r, a measurement by the ratio l_r/l_b can provide information as to any correction that should be applied to the first named measurement as a result of the presence of such background radiation or of said attenuation parameter.

For example, if an unwanted background or regional noise interference of strength B is present at all detectors, then the signal from detector l_r will be raised from l_r to (l_r+B), and similarly for each of the other detectors in the system; and in the substantially colinear array of three detectors just discussed, the output signals from the three detectors would be increased from l_r, l_a, and l_b to (l_r+B), (l_a+B), and (l_b+B). For any one detector the observed ratio of signal outputs would be changed by this background from, for example, the value l_r/l_a to the value

$$\frac{l_r+B}{l_a+B}=\frac{l_r}{l_a}\left[l-\left(\frac{B}{l_a}-\frac{B}{l_r}\right)+\text{quadratic and higher terms}\right]$$

In many applications, the correction terms will be negligible. Especially in applications which involve the difference of two such ratios there will be an almost complete cancellation of even a relatively large background. Whenever desired, the background can be completely eliminated by means of one extra detector. Thus, with three detectors we can subtract the outputs from the detectors taken in pairs and then form the ratios of these differences.

Algebraically, this corresponds to

$$\frac{(l_r+B)-(l_a+B)}{(l_r+B)-(l_b+B)}=\frac{l_r-l_a}{l_r-l_b}$$

and this ratio is completely independent of background. For the example of three substantially colinear detectors at separations a and b, as discussed hereinbefore, this ratio of the differences has the exact value:—

$$\frac{l_r-l_a}{l_r-l_b}=\frac{l-[r/(r+a)]^2\,e^{-\mu a}}{l-[r/(r+b)]^2\,e^{-\mu b}}$$

which again determines the range r in terms of known parameters, and with full and complete elimination of all background or noise effects.

The explicit discussion just given of background or noise elimination through the addition of one detector to the system is a specific illustration of a broad general principle; namely, that the number of independent detectors used (either by actual installation or by moving one or more actual detectors to new locations in the system) must always equal or exceed the number of unknown parameters. Thus, three detectors can measure (or eliminate) three parameters such as source strength J, range r, and azimuth θ.

If background is a problem in any specific embodiment of the method, then one more detector location provides the input information to eliminate or, if desired, to measure the background. Similarly if the degree of attenuation between detectors is significant, one more detector location will eliminate or evaluate this parameter.

Thus, in general, when the number of detector locations just equals the number of unknown parameters, the solution for each parameter is accessible. This is equivalent to recalling that n independent and simultaneous equations suffice to give unique solutions for n variables. If now the number of detector locations is increased by one over and above the number of unknown parameters, we have an overdetermined system, exactly like n+1 equations in only n unknowns. Such an overdetermined system can yield unique solutions for the n unknown parameters only if all the equations are mutually consistent and correct. The one (or more) extra detector locations provides redundant information just as does the (n+l)th equation. This feature of partial redundancy, through the provision of at least one more detector location than the minimum number required, provides an overall check on the operation integrity of the entire system.

Lastly, the above-described embodiment of the invention also enables a facile determination of the rate of closure of each of the range or distance r, the bearing angle θ and the elevation angle ϕ. As an illustration, the rate of closure of the range r is shown effected by feeding the output 13′ of the summer 13 to a time differentiation circuit 20 to obtain a signal representing the differentiation

$$d\left[\frac{l_r}{l_b}+\frac{l_r}{l_a}\right]/dt.$$

It will be recalled as above explained that the said sum of the ratios is almost entirely dependent upon the range r so that this differential output is a measure of the rate of change or closure of the range or distance r. This may of course be indicated in any desired closure rate meter at 22.

Similarly, since the difference of the ratios in the system of Figs. 1 and 2, as before explained, varies proportionately with the bearing angle, the output 11′ of the subtractor 11 may be differentiated as at 24 to indicate the rate of change of bearing angle in a similar angular rate meter 26. The rate of variation of elevation angle may also be obtained by differentiating the output of the ratio circuit 21 and indicating the same on a similar rate meter 30.

Though the aircraft 1 provides a means, if desired, for moving the detectors as a unit in azimuth and elevation, in the other systems it may be desired to mount the detectors for rotational movement as schematically illustrated at R in Fig. 2. Similarly, rocking in an elevational plane may be effected. It may also be desired to effect movement of the detectors toward one another as schematically illustrated by the arrows A in Fig. 2. If, for example, the detectors are mounted on a track, this movement toward and away from each other may readily be effected in a well-

known manner as by a motor driven rack and pinion, or other equivalent mechanism, not shown. One useful purpose in changing the distance, a, between the detectors l_r and l_a, for example, would be to provide an internal check on the reading of range r obtained from two detectors at separation a. If the same range is not obtained when a different separation is used, then (in the absence of equipment failure) the difference can be used to correct for the effect (if present) of background or noise in the system or of a significantly large attenuation coefficient in the medium between the detectors.

Movement of one or more detectors in the system to different detector sites, points or positions, is an operational equivalent of placing additional detectors at such sites, points or positions in the system. The word " detector " as used herein is thus to be interpreted as a detector location, site or point occupied by an actual detector at the time when readings which involve this site are taken, although an actual detector may be moved out of this site when readings at this site are not being taken.

WHAT WE CLAIM IS:—

1. An aircraft guidance system responsive to energy radiated from a given source and having an intensity decreasing with distance from the source in accordance with the function generally represented as $f(r, \mu)$, where r is distance from the source and μ is an attenuation parameter determined by the type of the radiant energy and the medium through which it is radiated, the system comprising three radiant energy detectors differently located on the aircraft and the outputs of which are paired so as to produce two intensity ratio measurements of the radiant energy incident on the detectors, dependent respectively on the azimuth angle and range of the aircraft with respect to the given source, and means for expressing the intensity ratio measurements in accordance with a predetermined relationship, to indicate said azimuth angle and said range of the aircraft.

2. An aircraft guidance system according to Claim 1, wherein a fourth detector is employed located on the aircraft so as to produce together with one of said three detectors, an intensity ratio measurement dependent upon the elevation angle of the aircraft with respect to the source, for any given range and for any given azimuth angle of the aircraft with respect to the source; and wherein said means comprise means for expressing the latter intensity ratio measurement in accordance with a predetermined relationship, to indicate the elevation angle of the aircraft with respect to the source.

3. An aircraft guidance system according to Claim 1 or Claim 2, wherein means are provided for correcting the intensity ratio measurements for the presence of background energy.

4. An aircraft guidance system according to any of the preceding Claims, wherein the three detectors are disposed respectively to occupy the corners of a triangle lying in a plane parallel to the longitudinal plane of the aircraft.

5. An aircraft guidance system according to Claim 4 and Claim 5, wherein the correcting means comprise means for subtracting the detector outputs of each pair providing an intensity ratio measurement and for expressing the differences formed by subtraction of one pair of outputs as ratios with the differences formed by subtraction of the other pair of outputs.

6. An aircraft guidance system according to any of the preceding Claims responsive to radiant energy of the type having said predetermined function $f(r, \mu)$ substantially given by $\frac{e^{-\mu r}}{r^n}$, wherein the range r is expressed according to the following relationships:—

$$\frac{l_r}{l_a} = \left(l + \frac{a}{r}\right)^n e^{\mu a}$$

and

$$\frac{l_r}{l_b} = \left(l + \frac{b}{r}\right)^n e^{\mu b},$$

where n is any integral number or fraction, a is the distance between two of the detectors, b is the distance between one of those two detectors and the third detector, and l_r, l_a, l_b are respectively the intensities of the energy detected by the said one detector and the respective other two detectors.

7. An aircraft guidance system according to Claim 6 wherein which $n=2$ and the detectors are disposed to occupy the corners of an equilateral triangle lying parallel to the longitudinal plane of the aircraft wherein $a=b$, with the said one detector being the one from which the range to the source is to be measured, with the other two detectors being at respective distances r_a and r_b from the source; and wherein the azimuth angle is expressed according to the following relationships:

$$\frac{l_r}{l_a} = \left[l + \left(\frac{a}{r}\right)^2 - \frac{2a}{r} \cos (150^\circ - \theta)\right] e^{\mu(r_a - r)}$$

$$\frac{I_r}{I_b}=\left[1+\left(\frac{a}{r}\right)^2-\frac{2a}{r}\cos(150^\circ+\theta)\right]e^{\mu(r_b-r)},$$

where θ is the azimuth angle.

8. An aircraft guidance system according to Claim 7 wherein $\mu(r_a-r)$ and $\mu(r_b-r)$ are small compared with unity and means are provided for the simultaneous solution of the said expressions for $\frac{I_r}{I_a}$ and $\frac{I_r}{I_b}$, thereby to indicate the distance r and angle θ.

9. An aircraft guidance system according to any of the preceding Claims, wherein means are provided for determining from an intensity ratio measurement, the rate of change of the range r, thereby to indicate the rate of change closure between the aircraft and the source.

10. An aircraft guidance system according to Claim 9 wherein the determining means comprises means for differentiating the sum of said ratio.

11. An aircraft guidance system according to any of the preceding Claims 2 to 10 wherein means are provided for determining from the intensity ratio measurements, the rate of change of at least one of the said relative bearing and elevation angles, thereby to indicate the rate of closure of said angles as the distance between the first and second objects changes.

12. An aircraft guidance system according to Claim 11, wherein the determining means comprise means for differentiating the difference of the said ratios.

13. An aircraft guidance system according to any of the preceding Claims, where computing means are provided wherein the said intensity ratio measurements of the three detectors are entered as co-ordinates therein, the range r being indicated by the coincidence of the co-ordinates with predetermined data corresponding to contours of successive values of the distance.

14. An aircraft guidance system according to Claim 13, wherein the computing means are further provided with predetermined data corresponding to successively increasing lines intersecting said contours, for indicating by coincidence with said co-ordinates, the angle between aircraft and the source in the plane formed by the three detectors.

15. An aircraft guidance system according to Claim 13 or 14, wherein the computing means are provided with means for determining the sum and difference of the intensity ratio measurements and entering the same into the computing means is co-ordinates, the range r being indicated by the coincidence of the co-ordinates with predetermined data corresponding to contours of successive values of the distance.

16. An aircraft guidance system according to Claim 2 and any of the preceding Claims 13 to 15, wherein the computing means are such as to provide for entry thereinto as a co-ordinate of the intensity ratio measurement produced by the fourth detector and said one of the three detectors, the computing means having predetermined data corresponding to contours of successive values of the range r and means for indicating coincidence between said one co-ordinate and the data corresponding to the contours representing the value of the range r in order to determine the other co-ordinate, thereby indicating as such other co-ordinate the elevation angle of the aircraft with respect to the source.

17. An aircraft guidance system according to Claim 1 substantially as hereinbefore described with reference to the accompanying drawings.

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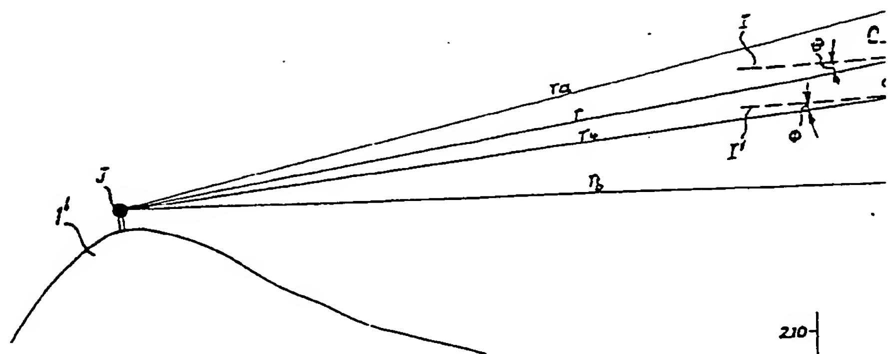


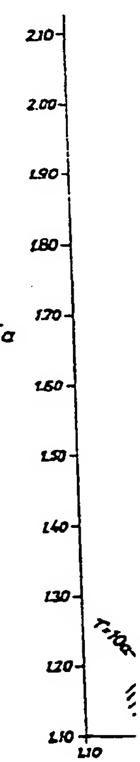


FIG. 3

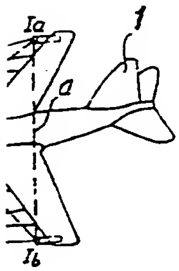
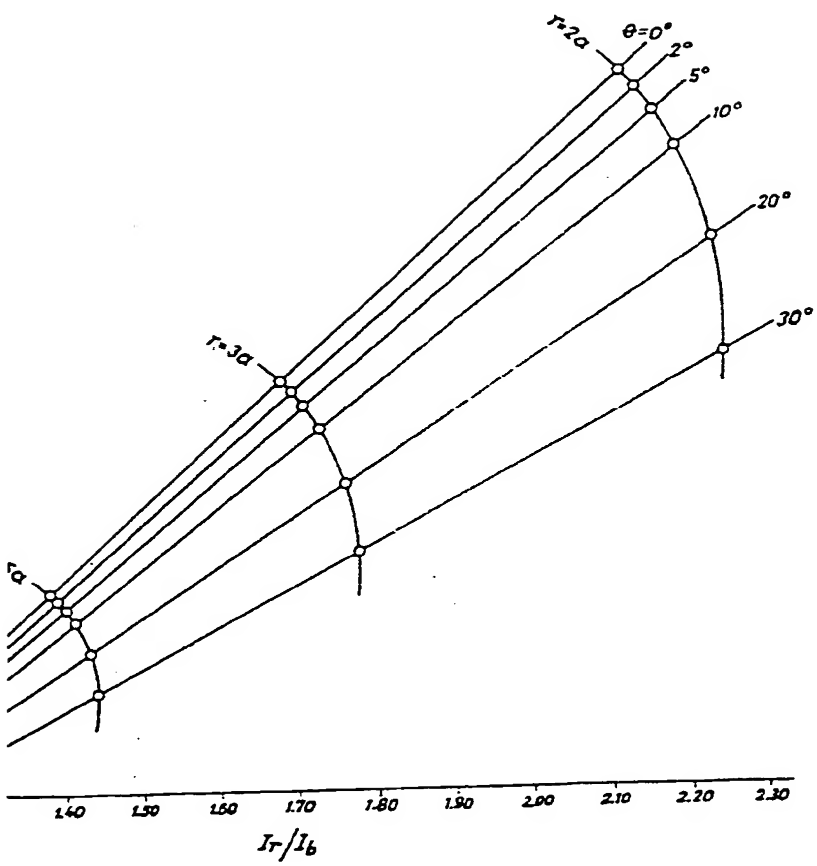

Ia
1
a
Ib

FIG. 1


r=2a
θ=0°
2°
5°
10°
20°
30°
r=3a
1.40
1.50
1.60
1.70
1.80
1.90
2.00
2.10
2.20
2.30
Ir/Ib

1176199 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

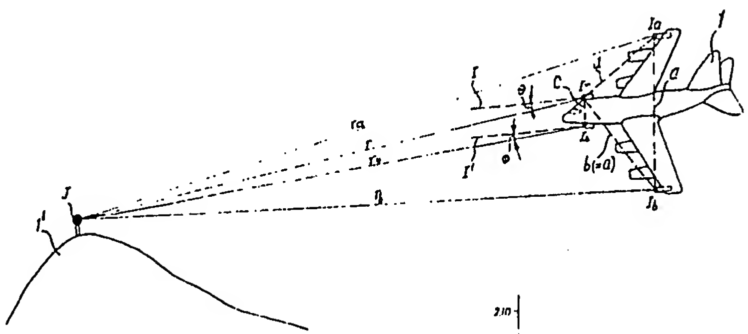


FIG 1

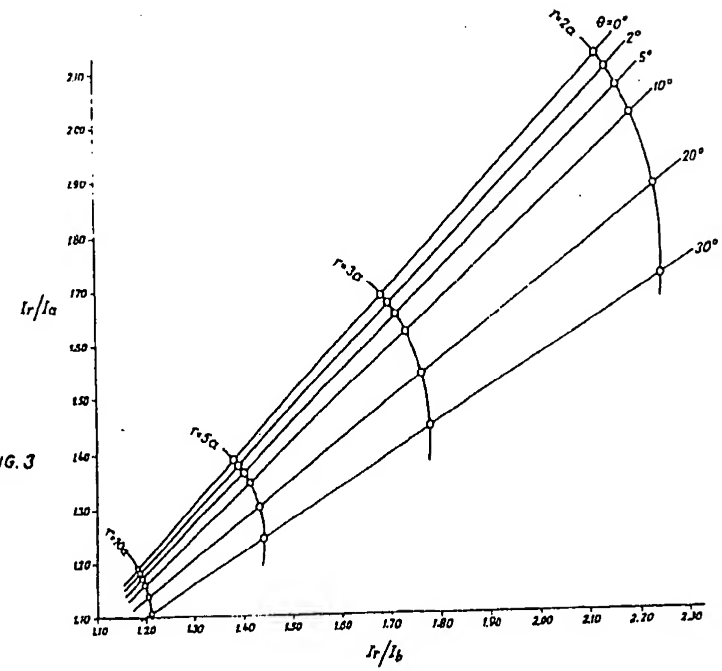
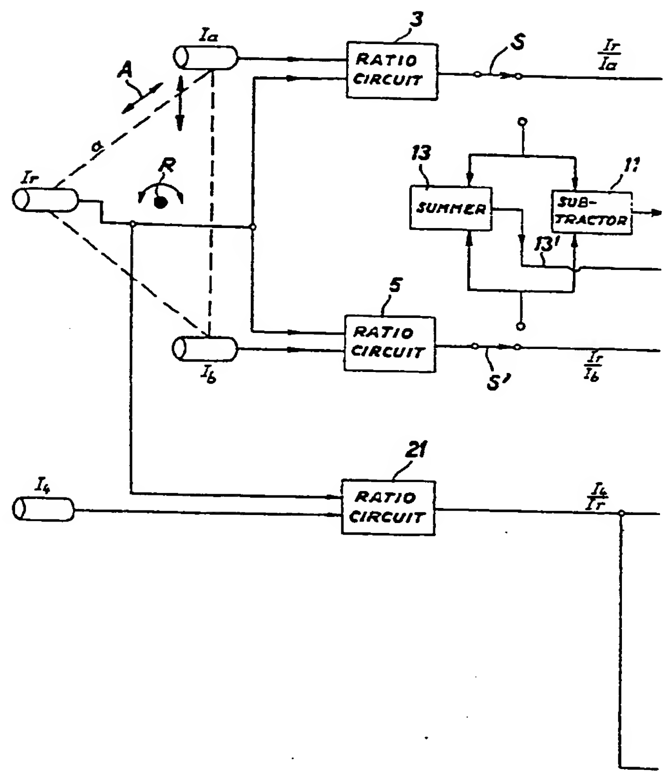


FIG. 3



3
RATIO CIRCUIT
S
Ir/Ia
A
a
R
Ir
13
SUMMER
11
SUB-TRACTOR
13'
5
RATIO CIRCUIT
Ir/Ib
S'
21
RATIO CIRCUIT
I4/Ir
I4

FIG. 2

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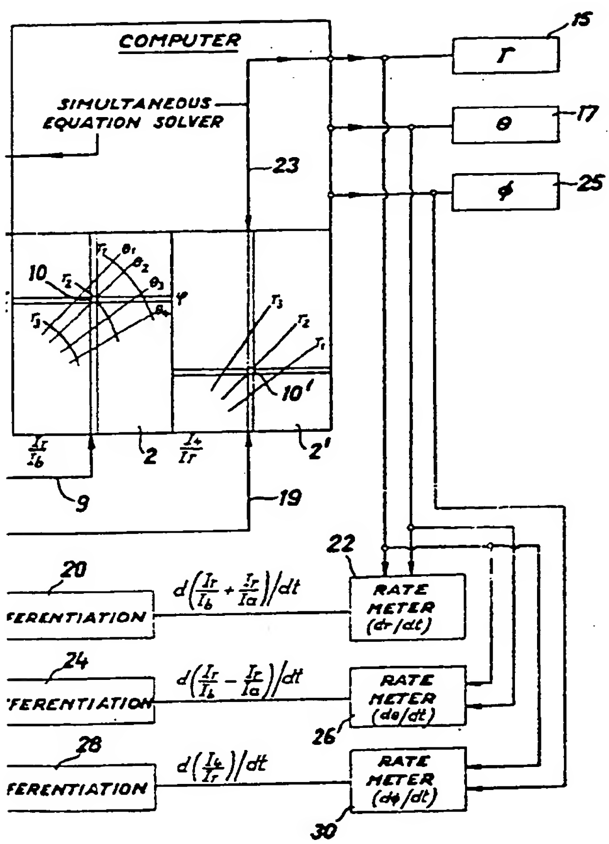
Sheet 2



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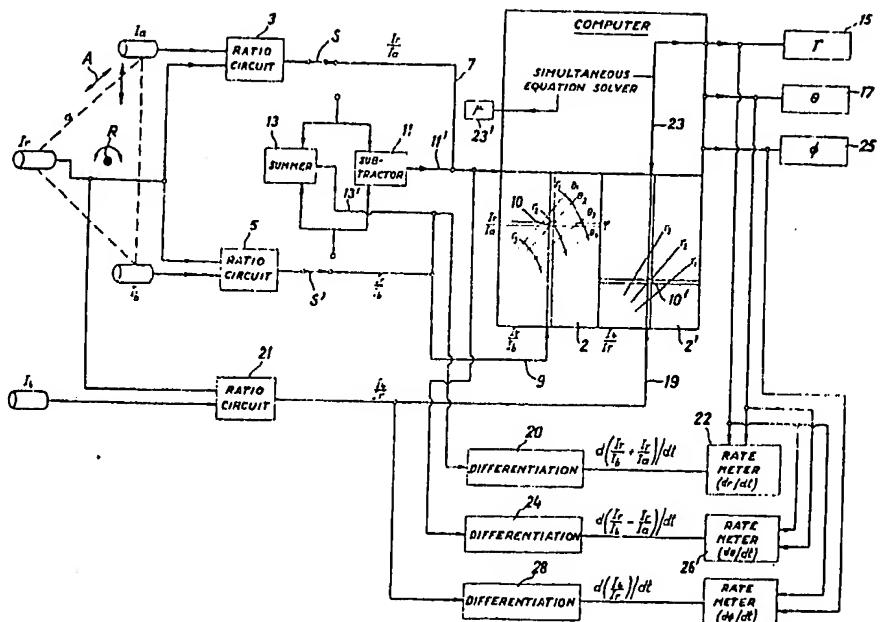
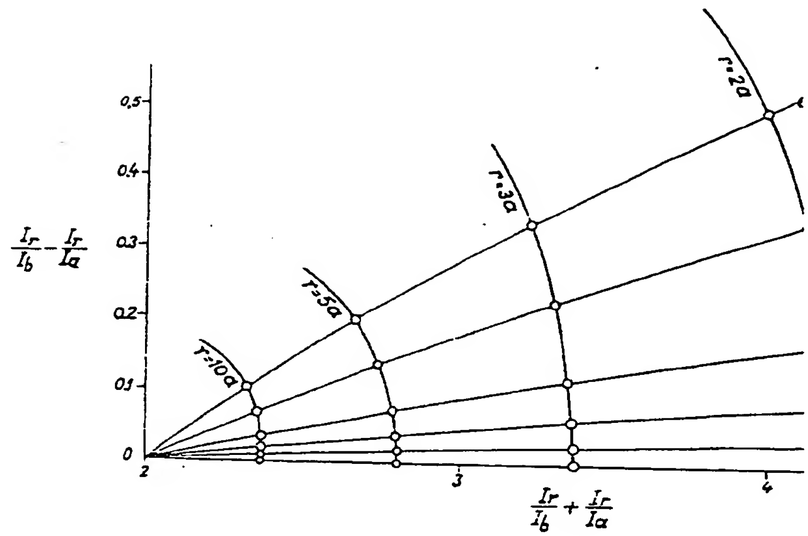


FIG. 2

FIG. 4



0,5
0,4
0,3
0,2
0,1
0
2
3
4
$\frac{I_r}{I_b} - \frac{I_r}{I_a}$
$\frac{I_r}{I_b} + \frac{I_r}{I_a}$
r=10a
r=5a
r=3a
r=2a

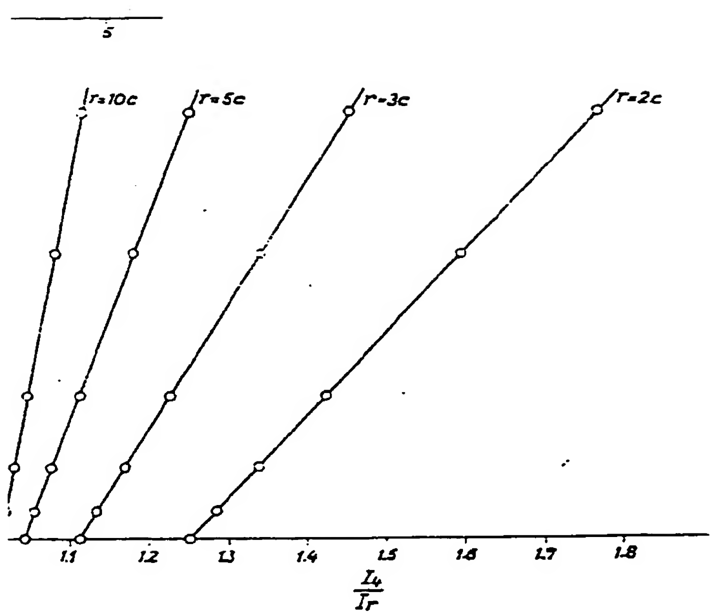


FIG. 5

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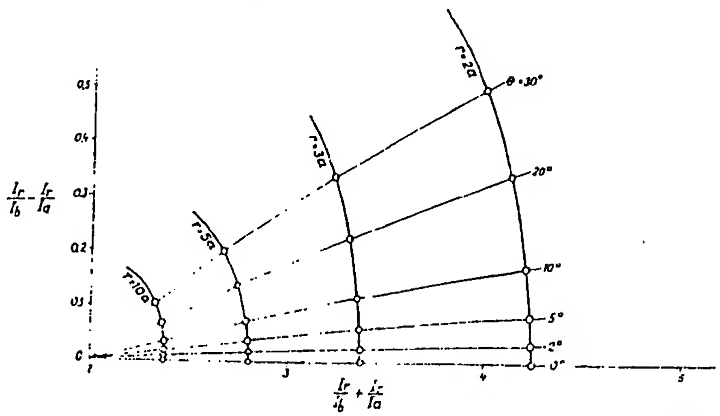
Sheet 3

FIG. 4



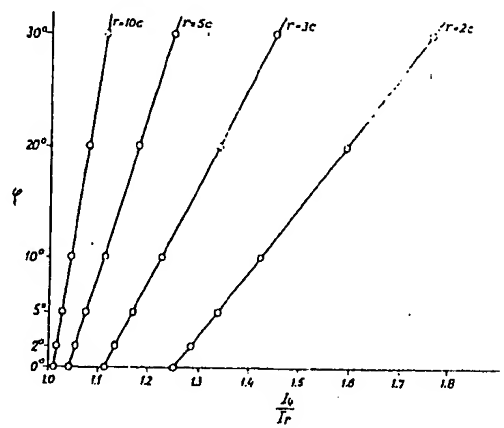


FIG. 5